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On the abundance and spatial distribution of *Illex coindetii* (Cephalopoda: Ommastrephidae) and *Eledone moschata* (Cephalopoda: Octopodidae) in the Sardinian Seas (central-western Mediterranean) - A preliminary and qualitative investigation with special attention to some environmental constraints

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Abstract

Abundance indexes and frequency of positive hauls data obtained for *Illex coindetii* and *Eledone moschata* from eight Mediterranean experimental trawl surveys carried out in the Sardinia Seas were analysed with an explorative methodology. Two sets of yearly surveys (homogeneous among them but different when considering the two groups) were thereby identified and the relative species density (N/km^2) GIS distribution maps computed. A trawl survey, "anomalous" if compared to the others of the considered historical series, was put in evidence, the anomaly resulting in a very high recruitment pulse for *Illex coindetii*.

Given the role of environmental factors (e.g., water temperature, currents regimes, up-welling events, etc.) on cephalopods life cycles, Sea Surface Temperature (SST) images for each month of a historical series of years, i.e. 1993-2001, including those of the trawl surveys considered, were gathered and qualitatively analysed to investigate SST relationship with the observed abundance/frequency fluctuations. Basic information available on the currents systems characterizing Sardinia waters was also collected and analysed.

Results did not show a clear qualitative relationship between SST and the observed general variability, but evidenced a good correspondence between both species distribution and the analysed hydrological patterns. Very interestingly, however, the unusually high pulse of recruitment observed for *I. coindetii* during 1997, corresponded to unusually high SST values recorded during the period November 1996-April 1997, indicating a hydrological situation different from the usual pattern. These anomalous values could reflect the shifting toward north of the Algerian current and, consequently, of the frontal zone off the western Sardinian coasts, occurred from 1996 to 1998. This, in turn, could have generated/determined optimal conditions for the eggs development and hatching (e.g., salinity, nutrients and temperature favourable conditions), thus the recruitment pulse observed.

Riassunto

Sono sempre più numerose le evidenze a favore dell'influenza che i fattori ambientali (ad esempio, temperatura dell'acqua, correnti, fenomeni di *up-welling*, etc.) hanno sui cicli vitali dei cefalopodi, in particolare sulle variazioni in abbondanza e distribuzione delle specie. Alla luce di ciò, nel presente lavoro si è tentato di interpretare la variabilità di distribuzione spazio-temporale osservata nei mari sardi per le due specie *Eledone moschata* e *Illex coindetii* prendendo in considerazione alcuni parametri ambientali, come la temperatura superficiale dell'acqua (SST) (di cui si è effettuata un'analisi qualitativa mensile dal 1993 al 2001) ed il sistema di correnti che caratterizza l'area di studio.

I dati provenienti da otto campagne di pesca sperimentali (1994-2001), effettuate nell'ambito del Progetto MEDITS, sono stati elaborati ed analizzati secondo una metodologia esplorativa che, sulla base degli indici di abbondanza (kg/km^2, N/km^2) e della frequenza delle cale positive, ha consentito di individuare, per entrambe le specie, due serie contrapposte di anni omogenei ed in particolare, per *I. coindetii*, un anno caratterizzato da valori "anomali" di abbondanza come conseguenza di un picco di reclutamento. Di tali anni sono state realizzate le mappe di distribuzione della densità (N/km^2), che sono quindi state confrontate qualitativamente con le mappe delle SST.

I risultati ottenuti non hanno messo in evidenza una chiara correlazione tra la SST e la generale variabilità di distribuzione osservata, che invece sembra trovare una buona corrispondenza con la complessa situazione idrologica della zona.

In particolare, tuttavia, in contrasto con la situazione generale delle temperature, i valori anomali registrati nel periodo novembre-dicembre '96 e marzo-aprile '97 (SST alte rispetto a quelle degli altri anni studiati), periodo precedente il picco di reclutamento osservato nell'estate '97, indicano il verificarsi di una situazione idrologica insolita nell'anno in questione, che in qualche modo ha influenzato positivamente l'abbondanza della specie. È possibile che questi valori di SST inusuali riflettano l'"anomalia" che tra il '96 e il '98 ha interessato la Corrente Algerina, il cui slittamento verso nord (e conseguente spostamento della zona di fronte nel versante occidentale della Sardegna) può aver creato condizioni ottimali di temperatura, salinità e nutrienti che hanno favorito lo sviluppo delle uova e delle prime fasi di vita dei giovani.

Key words

Cephalopods, Medits surveys, abundance, spatial distribution, environmental constraints, Mediterranean Sea.

Introduction

Cephalopod populations are conspicuous in showing dramatic yearly fluctuations in abundance and changes in spatial distribution. Besides the often unknown incidence of exploitation, environmental constraints have been shown to represent key factors underlying these phenomena and influencing cephalopod life cycles (e.g. Forsythe & van Heukelem, 1987; Mangold, 1987; Forsythe, 1993; Roberts & Sauer, 1994; Bakun & Csirke, 1998; Portner & Zielinski, 1998; Roberts, 1998; Brodziak & Hendrickson, 1999; Bellido et al., 2001; Dawe et al., 2000 and 2001; Jereb et al., 2001; Rodhouse, 2001). Among environmental factors, Sea Water Temperature (SWT) is determinant, especially in the early life stages (e.g. O'Dor et al., 1985; Fagundez & Robaina, 1992; Forsythe, 1993), and Sea Surface Temperature (SST) was recently identified as a possible tool to allow squid abundance prediction (Agnew et al., 2000, 2001 and 2002).
Analysing and understanding cephalopod life cycles driving factors represent fundamental items to provide any management action focused on these resources. In spite of the many efforts done towards this goal (e.g. Caddy, 1983; Saville, 1987; Bravo De Laguna, 1989; Boyle, 1990; Foucher et al., 1998; Lipinski, 1998; O'Dor, 1998), the methodological experience available is still poor, mainly due to our still poor knowledge of many biological aspects of the species life cycles (Roberts et al., 1998) and to the even more scanty and scattered knowledge of the oceanographic phenomena that characterise many areas of squid distributions.
Aim of this paper is to illustrate a way to study possible interactions between environmental factors and cephalopod distribution and abundance on the base of an exploratory analysis (Jereb et al., 2005). Towards this goal, the relation of SST with the abundance and spatial distribution of two species of Mediterranean cephalopods, the benthic musky octopus, *Eledone moschata* (Lamarck, 1798) (Cephalopoda: Octopodidae) and the epi-pelagic broadtail shortfin squid, *Illex coindetii* (Verany, 1839) (Cephalopoda: Ommastrephidae), obtained by applying this methodology, was analysed and the hydrological patterns of the investigated area were commented.
This study also represents an important step towards positive interactions between fisheries biologists and oceanographers, the unfortunate lack of which represented a negative constraint in the past.

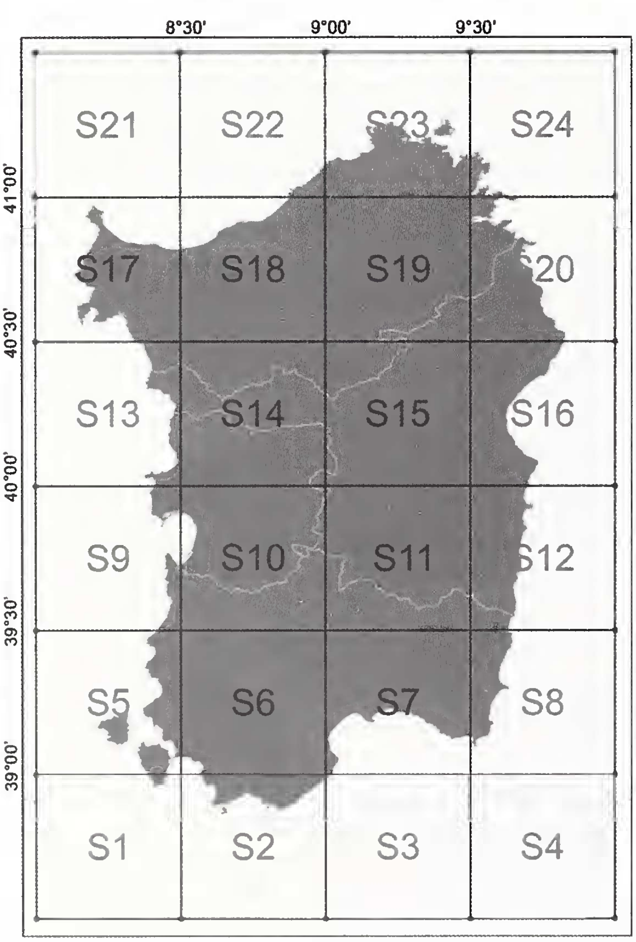

Fig. 1. Map of the studied area subdivided in sectors (S1-S24) by 0.5 degree of latitude and longitude.

Fig. 1. Suddivisione dell'area di studio in settori (S1-S24) aventi 0,5 gradi di latitudine e longitudine.

Material and Methods

Data of *Eledone moschata* and *Illex coindetii* gathered during eight bottom trawl surveys carried out in the Sardinian Seas within the MEDITS research project (Abellò et al., 2002) between 1994 and 2001, were analysed following Jereb et al. (2005). According to that, mean abundance index (AI) both in weigh (kg/ km^2, Biomass Index, BI) and number (N/ km^2, Density Index, DI) and the frequency of occurrence (f% of positive hauls) of the two species within the preferred bathymetric ranges were computed. These parameters were analysed by three-dimensional (3d-contour) graphic representations, on the base of which distribution maps assembling homogeneous years were computed. Sea Surface Temperature (SST) images were extracted from the recently released NASA Pathfinder global SST dataset available at 9 km resolution twice a day at the Physical Oceanography Distributed Active Archive Centre. Here night-time NOAA satellite passes have been chosen in order to avoid the afternoon warm-layer effect (Fairall et al., 1996) that in the Mediterranean Sea can occur in all seasons and for very light wind conditions can decouple the satellite measurements (skin measurements) from the "real" measurements (bulk measurements) (Böhm et al., 1991). The algorithm used to estimate SST here is the Pathfinder algorithm (Evans & Podestà, 1996), as validated by D'Ortenzio et al. (2000) for the Mediterranean Sea. After the processing and interpolation procedures, average SST values maps for each survey period were created using IDL 6.1 (Interactive Data Language) software. Also, the trends of the SST median value for each geographic sector (S1-S24) computed as indicated in **Fig. 1**, were analysed for the whole time range and the whole area. A qualitative comparison was performed to test the correspondence between the *abundance-and-frequency-distribution-pattern similarity* observed among surveys and the average SST obtained.

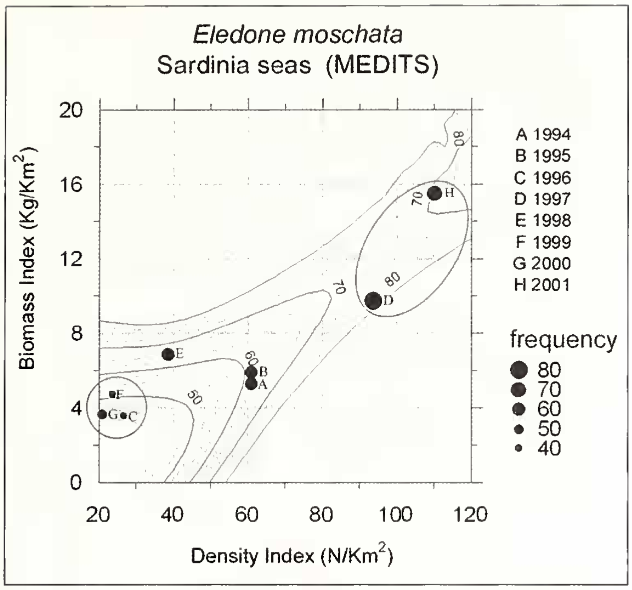

Fig. 2. Mean annual variation of abundance for *Eledone moschata*. The circles indicate the homogeneous years: 1996, 1999, 2000 (C, F, G) and 1997, 2001 (D, H).

Fig. 2. Variazione media annuale degli indici di abbondanza di *Eledone moschata*. Gli anni omogenei sono indicati dai cerchi: 1996, 1999, 2000 (C, F, G) e 1997, 2001 (D, H).

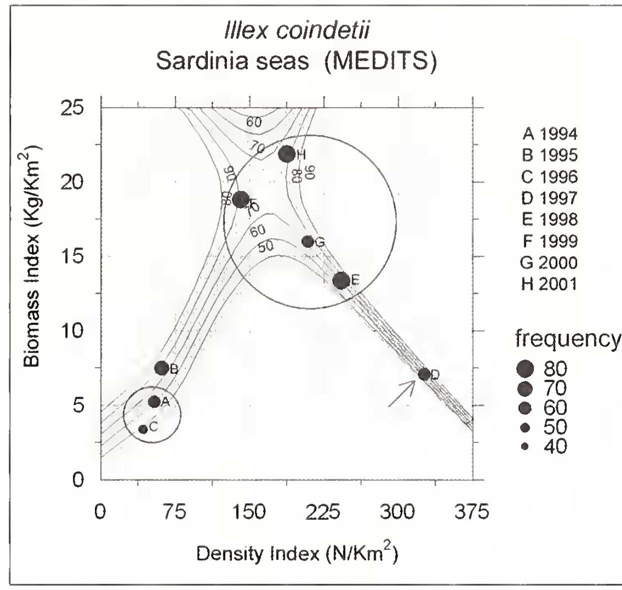

Fig. 3. Mean annual variation of abundance for *Illex coindetii*. The 1994, 1996 (A, C) and 1998, 1999, 2000, 2001 (E, F, G, H) homogeneous years are circled; the arrow points out the anomalous year 1997 (D).

Fig. 3. Variazione media annuale degli indici di abbondanza di *Illex coindetii*. Gli anni omogenei 1994, 1996 (A, C) e 1998, 1999, 2000, 2001 (E, F, G, H) sono indicati dai cerchi, l'anno anomalo 1997 (D) da una freccia.

Results

Mean abundance indices (in weight and number) and frequency of occurrence plots for the two species considered are shown in **Figs 2, 3**.

A different pattern is evident between the two species: a rather regular one for *Eledone moschata*, where the parameters are well correlated along a virtual axe (i.e. increasing DI and BI are generally linked to higher f%); a quite irregular one for *Illex coindetii*, where the parameters are poorly correlated (i.e. similar abundances may be linked to very different values of f%); here, an "anomalous" year characterized by a high presence of juveniles was clearly evidenced, i.e. 1997 (see arrow in **Fig. 3**). The two sets of yearly surveys detected (in principle, "high" values of BI, DI and f% versus "low" values), homogeneous among them but different when considering the two groups, are circled.

In **Figs 4, 5** the distribution maps obtained by using these grouped yearly surveys data are shown. The map corresponding to the anomalous survey for *I. coindetii* was also produced (**Fig. 6**). The spatial distribution of *E. moschata* shows an interesting discontinuity, with 3-4 main "focal points" symmetrically located along the corners of the island, while the central areas are rather poorly populatèd, especially on the eastern side. This is evident both in the case of the high density and frequency of occurrence when the animals are more concentrated (**Fig. 4 A**; the "black" area is smaller), and in years characterized by low abundance and high dispersion values years (**Fig. 4 B**; the "black" area is larger). *Illex coindetii* spatial distribution is characterized by a preferential location along the western coasts of Sardinia, with a lower dispersion rate in the "high values" survey years (**Fig. 5 A**).

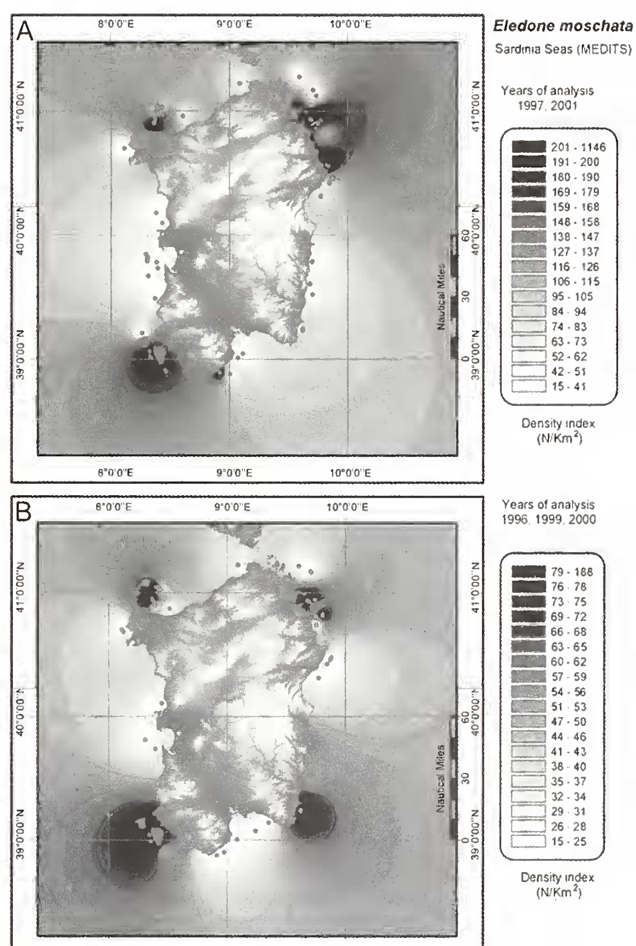

Fig. 4 A, B. GIS spatial distribution of *Eledone moschata* in the years with high (a) and low (b) density index values. The hauls allocation is indicated by dots.

Fig. 4 A, B. Rappresentazione GIS della distribuzione spaziale di *Eledone moschata* negli anni caratterizzati da alti (a) e bassi (b) indici di densità. I punti rappresentano l'allocazione delle cale.

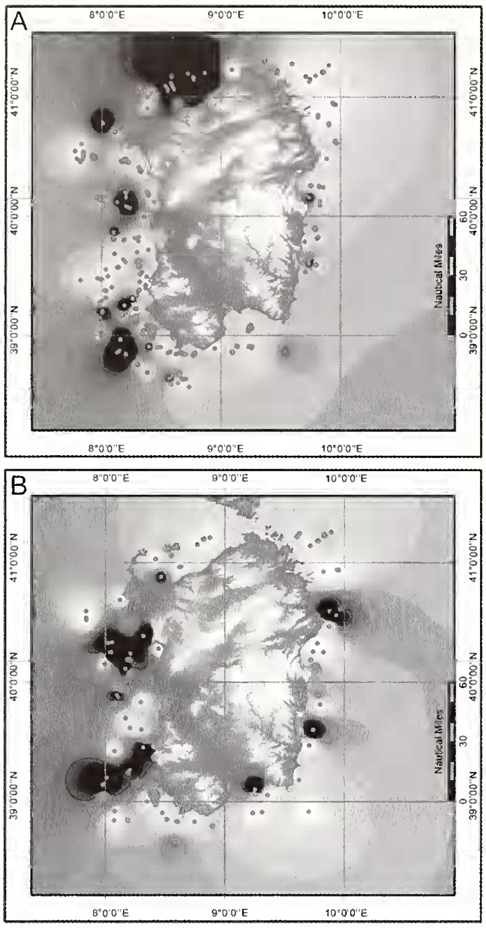

Fig. 5 A, B. GIS spatial distribution of *Illex coindetii* in the years with high (a) and low (b) density index values. The hauls allocation is indicated by dots.

Fig. 5 A, B. Rappresentazione GIS della distribuzione spaziale di *Illex coindetii* negli anni caratterizzati da alti (a) e bassi (b) indici di densità. I punti rappresentano l'allocazione delle cale.

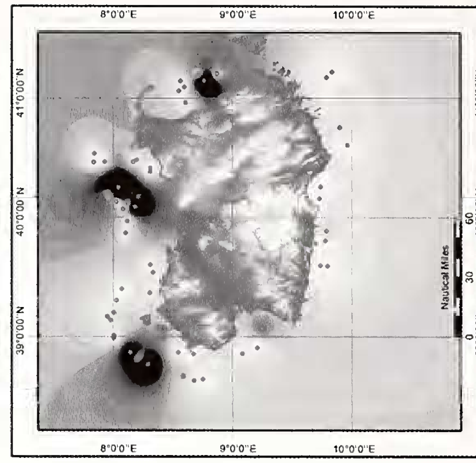

Fig. 6. GIS spatial distribution of *Illex coindetii* in the anomalous year (1997). The hauls allocation is indicated by dots.

Fig. 6. Rappresentazione GIS della distribuzione spaziale di *Illex coindetii* nell'anno anomalo (1997). I punti rappresentano l'allocazione delle cale.

Two (or three) main "focal points" are evident, confirmed by the distribution observed during 1997, where the high density registered was due to a huge pulse of recruits (**Fig. 6**). Again, the eastern side of the island seems less suitable for the species.

The average SST by survey period (**Fig. 7**) well reflects the little "shift-over" occurred in the time range covered during each fishing surveys: a warmer situation is shown for the years 1995, 1996 and 1997, then for the years 2000 and 2001, when the surveys were carried out from June till early August and in June-July respectively; a colder situation is evident for the years 1994, 1998 and 1999, when the surveys occurred during May-June (early July). In the colder periods it is better perceivable the pecu-

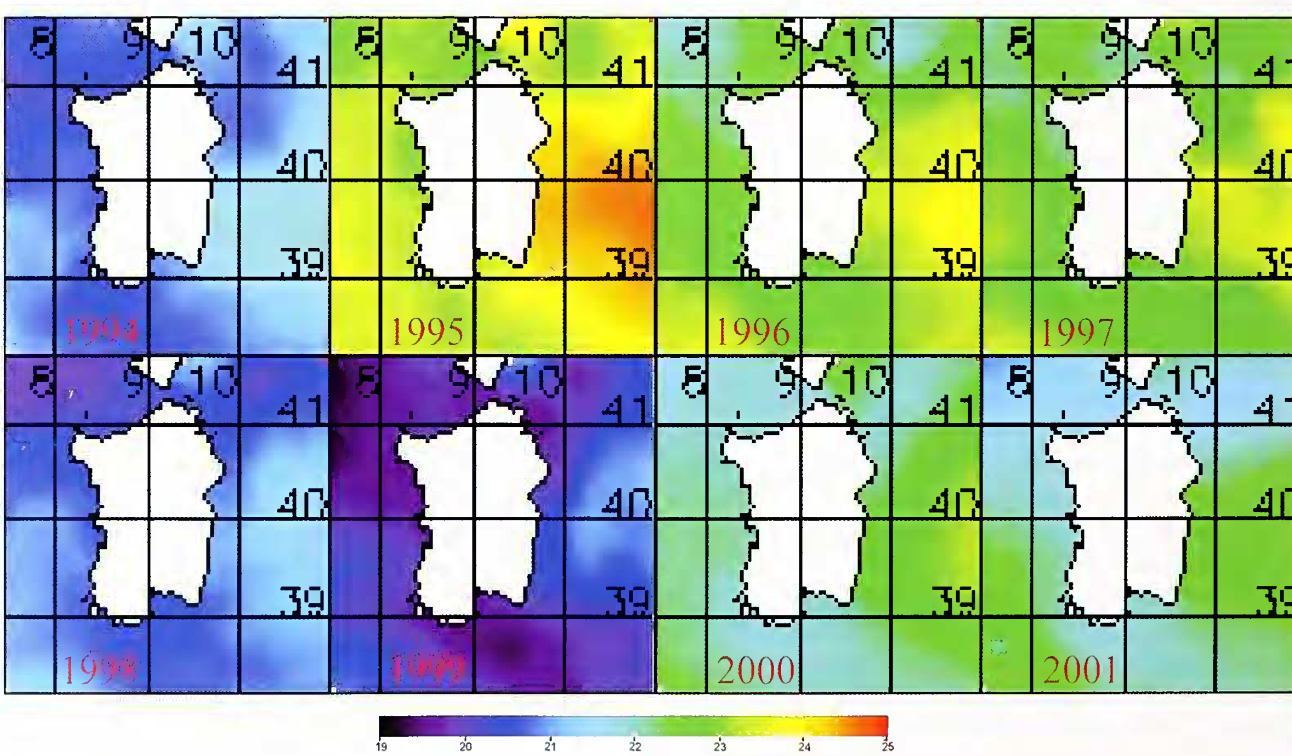

Fig. 7. Map of average SST around Sardinia for each trawl survey.

Fig. 7. Mappa delle SST medie dei mari circostanti la Sardegna durante i periodi di campionamento.

liar hydrological pattern described for the Sardinia waters, with superficial colder streams of waters flowing southwards along the Sardinia coasts in winters (Ausonic Cyclone - Winter Pattern). Interestingly, the noticeable warmer area located along the eastern side of the island in almost every map, roughly corresponded to the area where both species were less abundant. This warmer zone is already present in spring time but becomes more evident during summer (**Fig. 7**), when the thermal gradient is higher and the difference in the SST between the western and eastern side of the island is unmistakable.
As for the correlation between SST values and the species abundance, the analysis of the average SST by month during the years 1993-2001 showed no clearly oriented pattern to be related to the distributions observed. However, the occurrence of higher SST from November-December '96 to March-April '97 and from November-December '97 to March-April '98, was observed in all the western sectors, in contrast with the general pattern of the other years examined.
These high values represent a true anomaly for the area, the recorded SST having exceeded of over 1°C the values recorded for the same range of time during the other years of the historical time series analysed. This is remarkable in the sectors 1 and 13, those where the observed peak of juveniles occurred.
SST values computed for the sectors 1 and 18 in the years 1996 and 1997, were the maximum and minimum respectively registered in the western coast from 1996 to 1998 (**Fig. 8**).

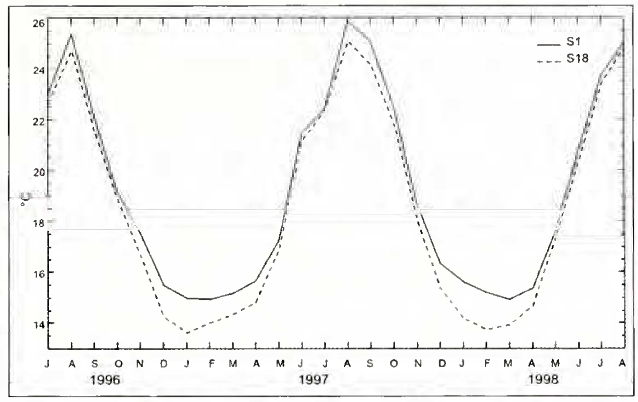

Fig. 8. Highest (S1) and lowest (S18) mean SST values recorded in the western Sardinian coast from 1996 to 1998.

Fig. 8. Valori massimi (S1) e minimi (S18) delle SST registrati nella costa occidentale della Sardegna dal 1996 al 1998.

Discussion

The used exploratory analysis allowed the identification of sets of years homogenous among them (and differing between the two different sets) for both *Illex coindetii* and *Eledone moschata*, species with highly different life cycles and ecological requirements. Therefore, it confirmed its validity as a tool for the investigation of cephalopod spatial and temporal distributions focused to enlighten affinities and discrepancies characterizing different yearly situations when considering a historical series. Yearly situations standing out of the "normal" values for any reason are also immediately noticed and noticeable, driving the attention of the investigators on the underlying causes of this anomaly.
The differences observed in the yearly distributions analysed, are mainly spatial (especially evident for *I. coindetii*) but also number-and-density related, and in both cases, as more generally observed on cephalopod species, are likely to depend on a combination of environmental factors (e.g. Roberts & Sauer, 1994; Dawe et al., 2000; Rodhouse, 2001). Among these, hydrological systems and currents regimes, driving forces determining water temperature and salinity changes and possible upwelling events, are those most probably responsible for most of the variability observed (e.g. Roberts & Sauer, 1994; Bakun & Csirke, 1998; Dawe et al., 2001).
In the present case, it is worth mentioning the peculiar geographical position of Sardinia, surrounded by a complex currents regime (e.g. Atzeni et al., 1997; Millot, 2005). In particular, the existence of four main circuits, the variability and movements/displacements of which (depending of several meteorological constraints and seasonality) create wide water flows and temperature and density variations: a cyclonic area in the north-western Mediterranean basin, the anticyclonic Algerian Current System in the south-western Mediterranean (characterized by a rather high instability), an anticyclone circuit in the Tyrrhenian Sea, and the so called Ausonic circuit (mainly affecting the superficial waters close to the Sardinia coasts during winter), consisting in a colder water flow southwards on both side of the island. The combination of these systems ideally divides the sea area around the island into at least three sub-areas, two along the west side, one along the east side; these, in turn, generate frontal zones that move accordingly to the system complex evolution.
Besides the already mentioned direct effects of SWT on many aspects of cephalopod life cycles, its non-direct relationships with cephalopod availability and abundance also have to be considered. SWT changes, in fact, can be indicative of important changes in many different oceanographic constraints (e.g. wind systems, up-welling events or other sources currents) with concomitant changes in the related ecosystem, therefore indirectly being correlated to cephalopod populations variation. SST, in particular, is a good example of such kinds of *indirect indicators*, its relationship with important cephalopod life cycle phases having being recently supported by numerous observations (e.g. Agnew et al., 2000, 2001 and 2002; Dawe et al., 2000 and 2001; Arvanitidis et al., 2002; Katara & Palialexis, 2003), but mostly without determining the possible cause-and-effects relationships involved.
Present lack of direct relationships between SSTs and the observed distributions, therefore, only stimulates further analyses; these will have to deepen the understanding of the interesting oceanographic patterns observed in the Sardinia waters, the preliminary analysis of which seems in good agreement with the observed species distribution patterns, with special reference to the western

side of the island that seems a particularly suitable environment for both species.

As for the unusually high pulse of recruitment observed for *I. coindetii* during 1997 (essentially during July of that year), a corresponding anomaly in the SSTs recorded in the preceding range of time was in fact observed: high temperature values (in some sectors exceeding of over 1°C those of the other years of the historical series examined) were recorded during winter '96 and spring '97 and winter '97 and spring '98. These unusual SST values may also reflect the anomalous situation reported by Millot (2005) in the Algerian cyclonic regimen, characterized by a shift of the Algerian current toward north from 1996 to 1998, and, consequently of the frontal of zone off the western Sardinian coasts.

According to what is known of the biology and eggs development of *Illex* species (e.g., Boletzky et al., 1973; Dawe & Beck, 1985; O'Dor et al., 1985), to the recent observation on the relationship between recruitment and SST (e.g. Agnew et al., 2000; Arvanitidis et al., 2002) and, more generally, between recruitment and oceanographic regimes (e.g. Dawe et al., 2000; Rodhouse, 2001), both the anomalous SST values and the mentioned concurrent oceanographic events (which in turn, may be linked to each other) are likely to be linked to the unusual recruitment observed in 1997. The absence of another peak of recruitment in 1998 is not surprising, the onset of the "anomalous" situation (i.e. what occurred during winter 1996-early spring 1997) being the "trigger" that generates the evident biological response.

Although preliminary, since essentially qualitative, results support the potential of water temperature and oceanographic events as key elements to investigate cephalopod life cycles also by using trawl surveys data and independently on the species considered.

Obviously, a quantitative analysis, possibly considering also other parameters, like temperature along the water column (e.g. Ragonese et al., in press), salinity and/or chlorophyll concentration (e.g. Katara & Palialexis, 2003), is necessary to validate the hereby reported qualitative evidences. The already mentioned desirable cooperation between biologists and oceanographers will help to obtain a more comprehensive understanding of the observed phenomena.

Acknowledgements

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